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RESEARCH AND EDUCATION

Staining and bleaching susceptibility of zirconia-reinforced lithium silicate glass-ceramics with different thicknesses, translucencies, and fabrication methods

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ABSTRACT

Statement of problem. The influence of different thicknesses, translucencies, and fabrication methods on the spectrophotometric and topographical properties of zirconia-reinforced lithium silicate glass-ceramics (ZLSs) for dental restorations remains unclear.

Purpose. The purpose of this in vitro study was to investigate the effect of thicknesses, translucencies, and fabrication methods on the color stability, translucency parameter, opalescence parameter, whiteness stability, transmitted irradiance, light transmittance, opacity, gloss, and roughness of ZLSs exposed to coffee staining and bleaching treatments.

Material and methods. Two pressable ZLSs (VITA AMBRIA, VA and Celtra Press, CP) and 2 machinable ZLSs (VITA Suprinity, VS and Celtra Duo, CD) were examined at high translucency (HT) and low translucency (LT) levels in 2 thicknesses (n=160). The specimens were evaluated at baseline, after coffee staining, and after bleaching. The color stability (ΔE2000), translucency parameter (TP), opalescence parameter (OP), whiteness index (WI_D), and whiteness stability (ΔWI_D) were measured with a spectrophotometer. Transmitted irradiance (I_t), light transmission (T), and opacity (O) were obtained from a light-polymerizing unit and a polymerization light collection device. Roughness stability (ΔSa%) was determined with an optical profilometer, and gloss stability (ΔGU%) was recorded with a gloss meter. Data of ΔCIE2000, ΔWI_D, ΔSa%, and ΔGU% were analyzed by 4-way ANOVA, and data of the TP, OP, WI_D, I_t, T, and O were analyzed by repeated 4-way ANOVA (α=.05).

Results. VS-HT exceeded the ΔCIE2000 acceptability threshold after coffee staining and bleaching protocols. Pressable ZLSs exhibited greater color stability than machinable ZLSs. The 1-mm-thick VA, CP, and CD materials exceeded the ΔWI_D perceptibility threshold after bleaching. The highest TP and OP was displayed by the 1-mm-thick CP after bleaching. ΔGU increased after water storage and decreased after coffee staining and bleaching. ΔSa% significantly increased after bleaching ($P<.05$).

Conclusions. The color stability and other spectrophotometric properties of ZLSs depended on material thickness. The effects of ZLS fabrication methods and translucency levels on their measured properties were inconsistent. Subjecting 1-mm-thick ZLS materials to acidic media adversely impacted their stainability and surface texture. (J Prosthet Dent 2024;131:530.e1-e11)

Zirconia-reinforced lithium silicate ceramics (ZLSs) are available in pressable and machinable forms with intricate crystalline substructures that provide optimum mechanical and optical properties.[1,2] The incorporation of ZrO_2 into ZLSs acts as a secondary nucleating agent along with P_2O_5 as the primary nucleator, yielding a microstructure comprised of fine crystals that are uniformly arranged in a highly dense network.[3,4] Pressable ZLSs include Celtra Press (Dentsply Sirona) and the recently introduced VITA AMBRIA (VITA Zahnfabrik). This ZLS has been the subject of limited in vitro studies, but its manufacturer claims it is accurately color matched to VITA shade guides. However, evidence confirming its shade-matching ability is lacking.[1,2,5,6] Machinable ZLS blocks are

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Clinical Implications

The erosive potential of acidic media on the colorimetric and topographic properties of ZLS restorations should be considered. ZLS restorations should be thoroughly polished after prolonged contact with coffee beverages or bleaching mouthwashes.

offered in a partially crystallized form as VITA Suprinity (VITA Zahnfabrik) and a fully crystallized form as Celtra Duo (Dentsply Sirona). Firing is mandatory to foster crystallization in VITA Suprinity and is also recommended for Celtra Duo to enhance its mechanical properties by healing milling-induced defects without altering its optical properties.[1,7–10] While manufacturers' report standard compositions for all ZLS shades and translucencies, underlying dissimilarities may exist in their microstructure because of the differences in their performance as a function of translucencies and fabrication methods.[11–14] Moreover, crystal sizes have been reported to be larger in pressable and high translucency ZLSs than in machinable and low translucency products.[15]

An inverse relationship between ceramic thickness and light transmission has been established.[16,17] Nevertheless, in clinical practice, ZLS restoration thickness is constrained by the amount of tooth reduction permissible and available interocclusal space.[16] Ceramic color and topography has been directly related to the pH fluctuations within the oral environment.[18] Staining and changes in surface texture from coffee beverages has been investigated,[17,19–21] and coffee-induced tooth discoloration is a common reason for patients to seek whitening treatment. While bleaching mouthwash is marketed for natural teeth, its proximity may inadvertently affect adjacent dental materials.[22–24] The hydrogen peroxide in bleaching agents, releases oxidizing free radicals (OH and H) that break down organic pigmented molecules within the tooth structure.[25–27] While ceramics have been reported to be highly resistant to peroxide,[28] others have stated that H can penetrate ceramic surfaces by virtue of its small size and chemical reactivity, thereby producing whitening.[25]

The optical properties of ceramics are influenced by their crystal size, shape, composition, density, and refractive index (RI).[29] The low RI index of ZLSs (1.573) resembles that of tooth structures (1.540<RI<1.631),[30,31] providing ZLSs with high translucency despite their dense crystallinity.[32] The Commission Internationale de l'Eclairage (CIE) color difference formula CIEDE2000 was developed to eliminate discrepancies between perceived and computed color differences because it accounts for interactions between lightness, hue, and chroma.[33–35] The opalescence of ceramics occurs when the RI mismatch between crystalline and glassy matrix phases is ≥1.1, causing scattering of visible light, thus provoking a blue appearance under reflected light and an orange appearance under transmitted light.[36,37] Translucency and opalescence parameters computed from color coordinate differences against white and black backgrounds can be used to quantify the translucency and opalescence of ceramics.[38–44]

Whiteness is an important tool when comparing ceramics with tooth structure and measuring the efficacy of bleaching agents.[45–47] The most recent whitening index (WI_D) was formulated from the CIE color space via correlations between visual color perception and shade match guides.[48] Ceramic restorations with opacifiers such as zirconium oxides can cause light scattering that reduces light transmission and, in turn, increases opacity.[49] Moreover, ceramics attenuate light transmission from polymerizing units to the underlying photopolymerizable resin cements, thereby impacting bond strength and restoration longevity.[50–55]

Gloss is an optical trait used to describe the mirror-like luster of dental ceramics after surface finishing.[56] The gloss unit (GU) requirement for esthetic materials ranges from 40 to 60 to simulate that of enamel (40<GU<52).[57,58] To minimize plaque retention and human eye perception, the acceptable ceramics roughness is ≤0.2 µm.[59–61] Acidic beverages remove the superficial SiO_2 molecules of ceramics, resulting in rougher surfaces with higher stain susceptibility, altered light reflection, and reduced gloss.[62–65] Nonetheless, evidence regarding the effects of hydrogen peroxide bleaching agents on the surface texture of dental ceramics is controversial.[25,66,67]

The present study was designed to provide evidence of the effects of thickness, translucency, and fabrication method of ZLSs on their spectrophotometry and topography after storage in staining and bleaching media. The null hypotheses were that different thicknesses, translucencies, and fabrication techniques of ZLSs and their exposure to coffee and bleaching solutions would not influence their spectrophotometric or topographical properties.

MATERIAL AND METHODS

Four types of zirconia-reinforced lithium silicate glass-ceramics were examined in high (HT) and low (LT) translucency levels: VITA AMBRIA (VA), VITA Suprinity (VS), Celtra Press (CP), and Celtra Duo (CD) (Table 1).[2] Pressable ceramic ingots (VA and CP) were pressed using the lost wax technique and a pressing furnace (Vario Press 300e; Zubler Gerätebau GmbH) in accordance with each material's manufacturer instructions. Machinable ceramic blocks (VS and CD) were sectioned

Table 1. Experimental materials and manufacturers' information

Classification	Material	Chemical Composition (wt%)	Crystal Size (μm)
Zirconia-reinforced lithium silicate glass-ceramic	VITA AMBRIA (VA)	58-66% SiO_2, 12-16% Li_2O, 8-12% ZrO_2, 2-6% P_2O_5, 1-4% Al_2O_3, 1-4% K_2O, 1-4% B_2O_3, 0-4% CeO_2, 1-4% Tb_4O_7, < 1% V_2O_5, < 1% Er_2O_3, < 1% Pr_6O_{11}	2.5 - 3.5
	VITA Suprinity (VS)	56-64% SiO_2, 15-21% Li_2O, 8-12% ZrO_2, 3-8% P_2O_5, 1-4% Al_2O_3, 1-4% K_2O, 0-4% CeO_2, 0.1% La_2O_3, 0-6% pigments	0.5 - 0.7
	Celtra Press (CP)	58% SiO_2, 18.5% Li_2O, 10.1% ZrO_2, 5% P_2O_5, 1.9% Al_2O_3, 2% CeO_2, 1% Tb_4O_7	0.4 - 1.0
	Celtra Duo (CD)	58% SiO_2, 18.5% Li_2O, 10.1% ZrO_2, 5% P_2O_5, 1.9% Al_2O_3, 2%CeO_2, 1% Tb_4O_7	0.4 - 0.8
Whitening mouthwash	Crest 3D MultiCare	H_2O, 1.5% H_2O_2, $C_3H_8O_2$, $Na_6[(PO_3)_6]$ poloxamer, sodium citrate, sodium saccharin, and citric acid	n/a

with a precision saw (IsoMet 1000; Buehler) and then fired in a furnace (Programat EP5000; Ivoclar AG) per the manufacturers' recommended firing schedules. Specimens were then wet polished with 400- to 1200-grit silicon carbide papers (Metaserv 250 Grinder Polisher; Buehler). The final dimensions of the specimens (n=160) were 10×10 mm in 1- and 2-mm thicknesses, and dimensions were verified with a digital micrometer with ±0.05 mm tolerance (Digital micrometer IP65; Mitutoyo MC). Sample size was determined with a software program (G*power, v3.1.3; Heinrich Heine University Düsseldorf) where an eta-squared value of 0.06 was used to estimate effect sizes that obtain 82% power probability.[68] Specimens of each material were randomly divided into 2 subgroups by simple randomization with a computer program (IBM SPSS Statistics, v29.0; IBM Corp) into their allotted storage media: distilled water or coffee. The coffee solution was prepared by dissolving 3.6 g of instant coffee powder (Nescafe Classic; Nestle) in 300 mL of hot water of pH=4.8 (pH meter, Mettler Toledo; DELTA 340) and the immersion period was for 12 days, equivalent to 1 year of coffee consumption.[19,22] Immersed specimens were stored in an incubator (Heraeus Function Line; Kulzer GmbH) at 37 °C and solutions were replenished daily. After staining, specimens of both storage groups were subjected to bleaching by immersion in a whitening mouthwash (Crest 3D White Multicare; Procter Gamble) containing 1.5% hydrogen peroxide and with a pH of 4.9 for 12 hours in an incubator at 37 °C, simulating a year of rinsing with mouthwash.[69] The properties were measured at 3 time points: T_0 (baseline), T_1 (after staining), and T_2 (after bleaching) (Fig. 1).

A benchtop UV–visible light spectrophotometer (LabScan XE; Hunter Associates Laboratory Inc) with a D65 illuminant, 10-degree observer, and 5-mm aperture was used to scan specimens within the 400 to 700 nm wavelengths at 10-nm intervals. L*a*b* readings of ZLSs were

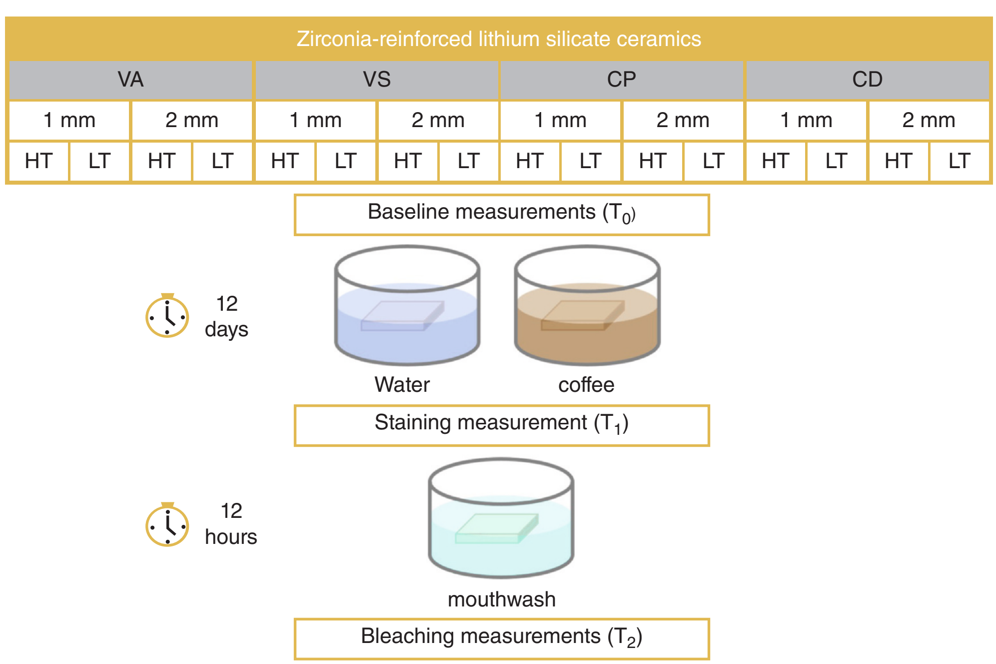

Figure 1. Experimental study design.

recorded, where L* denotes lightness (100) or darkness (0), a* the redness (> 0) or greenness (< 0), and b* the yellowness (> 0) or blueness (< 0). Three readings were measured for each ZLS against a black (L*=0.01, a*=−0.02, b*=0.01) and a white (L*=90.35, a*=−1.31, b*=−0.27) background. Color stability (ΔE2000) was measured as the differences in color coordinates against a black background after staining (T_1-T_0) and bleaching (T_2-T_0) using the equation

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L}{K_L S_L}\right)^2 + \left(\frac{\Delta C}{K_C S_C}\right)^2 + \left(\frac{\Delta H}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C}{K_C S_C}\right)\left(\frac{\Delta H}{K_H S_H}\right)},$$

where ΔL, ΔC, and ΔH indicate changes in lightness, chroma, and hue; RT is a rotation factor for chroma and hue; SL, SC, and SH are correction weighting factors for lightness, chroma, and hue; and KL, KC, and KH are parametric factors set as 1.33 Color differences were considered visually perceptible when ΔE2000>0.8 and clinically acceptable when ΔE2000<1.8.[70] The translucency parameter (TP) and opalescence parameter (OP) were calculated from the equations

$$TP = \sqrt{(L_B^* - L_W^*)^2 + (a_B^* - a_W^*)^2 + (b_B^* - b_W^*)^2} \text{ and } OP = \sqrt{(a_B^* - a_W^*)^2 + (b_B^* - b_W^*)^2},$$

where subscripts B and W refer to color coordinates against a black and a white background.[38] The whiteness index (WI_D)[48] of the ZLS specimens was calculated based on the L*, a*, and b* coordinates using the equation $WI_D = 0.511L^* - 2.324a^* - 1.100b^*$. Subsequently, ΔWI_D was calculated by $\Delta WI_D = WI_{D2} - WI_{D0}$, where subscripts 0 and 2 refer to measurements recorded at the T_0 and T_2 time points. Whiteness differences were considered visually perceptible when ΔWI_D>0.72 and acceptable when ΔWI_D<2.62.[71]

The incident irradiance (mW/cm^2) of a light-emitting diode light-polymerizing unit (Elipar S10; 3M ESPE) and the transmitted irradiance of ZLSs were measured with a polymerization light collection device (MARC-LC; BlueLight analytics). Before the measurements, the light-polymerizing unit was fully charged and fixed at 0 distance between its tip and the ceramic specimen. The transmitted irradiance (I_t) through each specimen was measured 3 times in a 20-second continuous light-polymerizing cycle. The irradiance needed to photopolymerize a light-polymerized resin cement is 800 mW/cm^2 in a 20-second exposure cycle.[72] Subsequently, ZLS light transmittance (T) and opacity (O)[73,74] were measured using the equations $T = \left(\frac{I_t}{I_0}\right)$ and $O = T^{-1} = \left(\frac{I_0}{I_t}\right)$, where I_t is the irradiance of light passing through the specimen and I_0 is the irradiance of incident light (1600 mW/cm^2).

The surface gloss of ZLS specimens was measured with a gloss meter (IG-331; Horiba) at a 20-degree projection angle as specified for high gloss surfaces.[75] Specimens were covered to eliminate external light, and 3 readings were recorded per specimen. Gloss was reported in Gloss Units (GU) and ranged from 0 (absolute nonreflective surface) to 100 (absolute reflective surface). Subsequently, ΔGU% was calculated after staining ($[(T_1\text{-}T_0)/T_0]\times100$) and bleaching ($[(T_2\text{-}T_0)/T_0]\times100$). A noncontact optical profilometer (Talysurf CLI 1000; Taylor Hobson Precision) was used to collect 3 roughness measurements per specimen from a 2×2-mm area at a 500 µm/second scanning rate. Roughness was reported in Sa (µm) roughness parameters, where Sa denotes the mean height deviation within a surface area, and the ΔSa% of ZLS was calculated after bleaching ($[(T_2\text{-}T_0)/T_0]\times100$).

The data normality of all properties was confirmed by the Kolmogorov-Smirnov test. The homogeneity of ΔCIE2000, ΔWI_D, ΔGU%, and ΔSa% was confirmed by the Levene test, and then the data were analyzed by 4-way ANOVA to evaluate the effects of thickness, translucency, fabrication method, and storage solution. The Mauchly test was used to verify the sphericity of TP, OP, WI_D, I_t, T, and O, and then the data were analyzed by repeated measures 4-way ANOVA with 4 between subject factors (translucency, thickness, fabrication method, and storage solution), and 1 within subject factor (treatment time). A statistical software program (IBM SPSS Statistics, v29.0; IBM Corp) was used for all statistical analysis (α=.05).

RESULTS

CIEL*a*b*coordinates at T_0 are listed in Table 2 and mapped in Figure 2, and ΔCIE2000 after staining and bleaching are plotted in Figure 3A. Four-way ANOVA revealed significant effects of thickness, fabrication, and storage solution (P<.001) on ZLS color stability (Table 3). HT-VS in 1 mm exceeded ΔCIE2000 acceptability threshold after coffee staining and bleaching protocols, and pressable ZLSs displayed less mean color change than machinable ZLSs. Figure 3B illustrates the mean TP values of ZLSs, where thickness and translucency significantly impacted TP (P<.01) (Table 4) and the highest TP was displayed by HT ZLSs in the 1-mm thickness. Results for OP are shown in Figure 3C, and repeated measures 4-way ANOVA identified a significant effect of ZLS thickness and fabrication method (P<.001) on their OP. Figure 4 demonstrates the WI_D for ZLSs at baseline and ΔWI_D after bleaching. Four-way ANOVA indicated that thickness, translucency, fabrication method, and storage solution significantly influenced ΔWI_D (P<.01) (Table 3). VA, CP, and CD in 1-mm thickness exceeded the ΔWI_D perceptibility threshold, and no ZLSs violated ΔWI_D acceptability threshold. Findings for the I_t of ZLSs are presented in Figure 5A, and repeated measures 4-way ANOVA identified that thickness and translucency significantly reduced

Table 2. CIE L*a*b* color coordinates of zirconia-reinforced lithium silicate ceramics at baseline

Material	Translucency	Thickness	L*	a*	b*
VA	HT	1 mm	64.1877	-1.138	6.166
		2 mm	55.7357	-0.862	3.689
	LT	1 mm	62.288	-0.5397	7.079
		2 mm	61.1633	0.11767	5.71833
VS	HT	1 mm	66.2543	-1.4113	7.50933
		2 mm	61.8463	-1.186	5.743
	LT	1 mm	67.3723	-1.3723	9.66233
		2 mm	64.3883	-1.0287	7.27433
CP	HT	1 mm	66.113	-1.5037	5.755
		2 mm	59.877	-1.3017	4.55533
	LT	1 mm	66.017	-1.2673	4.73733
		2 mm	61.5877	-1.0987	3.899
CD	HT	1 mm	63.2937	-0.7887	5.81767
		2 mm	56.9163	-0.776	4.22933
	LT	1 mm	67.1247	-0.8747	5.30067
		2 mm	59.2054	-0.9284	3.9491

CD, Celtra Duo; CP, Celtra Press; HT, high translucency; LT, low translucency; VA, VITA AMBRIA; VS, VITA Suprinity.

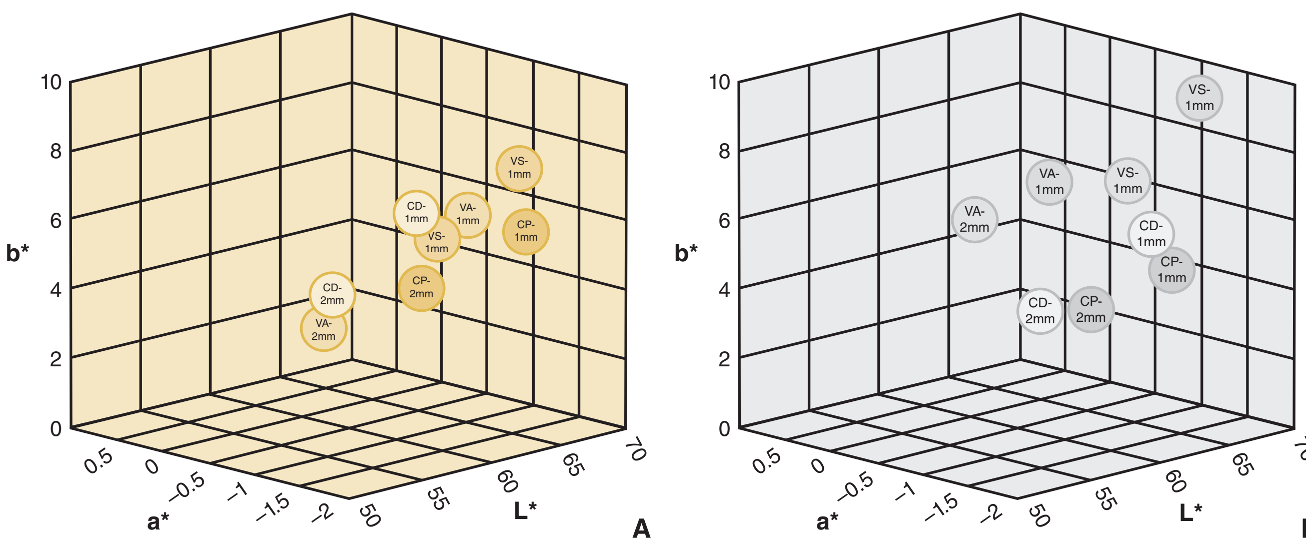

Figure 2. Zirconia-reinforced lithium silicate ceramics plotted within 3D CIEL*a*b* color space for different thicknesses and translucency levels. A, High translucency. B, Low translucency. CD, Celtra Duo; CP, Celtra Press; VA, VITA AMBRIA; VS, VITA Suprinity.

the I_t of ZLSs (P<.001) (Table 5). Repeated measures 4-way ANOVA indicated a significant effect of ZLS thickness, translucency, and fabrication method on their T (P<.05) (Table 5). The results for the O of ZLS are shown in Figure 5B, where significant effects of thickness and translucency were detected (P<.001) (Table 5). The ΔGU% results of ZLS after staining and bleaching are plotted in Figure 6A. Four-way ANOVA indicated a significant effect of storage solution (P<.001) on the ΔGU% at T_1 and of the fabrication method (P<.05) on the ΔGU% at T_1 and T_2. (Table 6). Results for ΔSa% at T_2 are illustrated in Figures 6B, and 4-way ANOVA revealed significant effects of translucency (P<.05) and storage solution (P<.001) on ΔSa% (Table 6).

DISCUSSION

The findings of the current study revealed that ZLSs of different thicknesses, translucencies, and fabrication methods significantly differed in their spectrophotometric and topographical properties. Moreover, all the measured properties of ZLSs were significantly influenced by immersion in acidic storage media. Hence, the null hypotheses that different thicknesses,

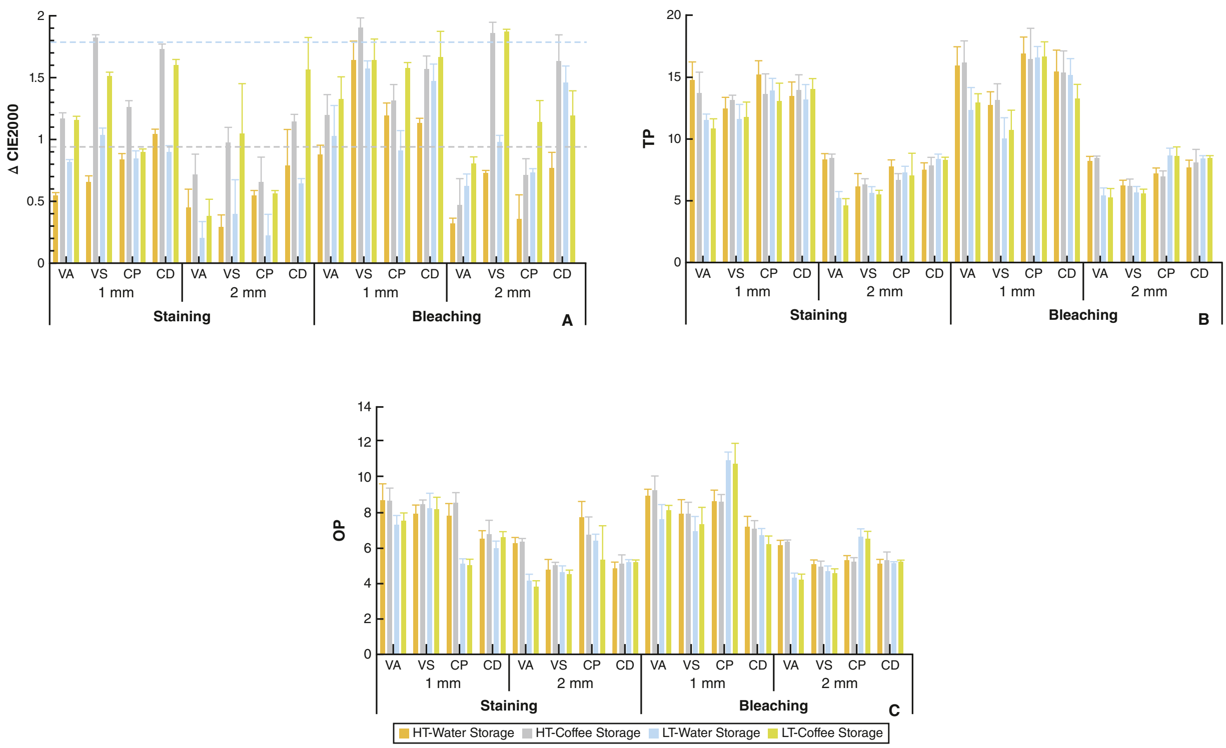

Figure 3. Zirconia-reinforced lithium silicate ceramics in different thicknesses and translucencies after staining and bleaching treatments. A, Color differences (ΔCIE2000) *Horizontal blue line* represents ΔCIE2000 acceptability threshold. *Horizontal gray line* represents ΔCIE2000 perceptibility threshold. B, Translucency parameter (TP). C, Opalescence parameter (OP). CD, Celtra Duo; CP, Celtra Press; HT, high translucency; LT, low translucency; VA, VITA AMBRIA; VS, VITA Suprinity.

Table 3. Four-way ANOVA table for ZLS color stability (ΔCIE2000) after staining (T_1), bleaching (T_2), and ZLS whiteness stability (ΔWI_D) after bleaching (T_2)

Parameter	Time	Source of Variation	Sum of Squares	df	F	*P*
ΔCIE2000	T_1	Thickness	4.621	1	31.291	<.001*
		Translucency	0.022	1	0.149	.700
		Fabrication method	16.804	1	113.781	<.001*
		Storage solution	5.773	1	39.087	<.001*
	T_2	Thickness	4.720	1	26.201	<.001*
		Translucency	0.396	1	2.198	.140
		Fabrication method	13.748	1	76.319	<.001*
		Storage solution	4.199	1	23.311	<.001*
ΔWI_D	T_2	Thickness	8.188		294.220	<.001*
		Translucency	0.257	1	9.251	.003*
		Fabrication method	0.595	1	21.394	<.001*
		Storage solution	1.185	1	42.570	<.001*

df, degree of freedom (N-1); ZLS, zirconia-reinforced lithium silicate glass-ceramic. *statistically significant ($P < .05$).

translucencies, and fabrication techniques of ZLSs and their exposure to coffee and bleaching solutions would not influence their spectrophotometric or topographical properties were rejected.

All ZLS specimen color measurements were made against white and black backgrounds to duplicate the light reflectance of teeth under intraoral conditions.[76] Despite standardizing the shade of all ZLS specimens (shade A1), differences were detected in the color coordinates between ZLS materials of similar thickness, translucency, and fabrication method (Fig. 2, Table 2). VS materials of 1-mm thickness exceeded the ΔCIE2000 acceptability threshold after coffee staining and after bleaching, whereas 2-mm-thick VS surpassed the threshold after bleaching of the coffee-stained specimens. The findings could be justified by the combined effect of coffee staining and the whitening mouthwash that affected VS specimens of 2-mm thickness, while staining per se did not cause color changes. However, pressable ZLSs (VA, CP) exhibited less stainability than the machinable ZLSs. These findings were consistent with those of previous

Table 4. Repeated measures four-way ANOVA table for the translucency parameter (TP), opalescence parameter (OP), and whiteness index (WI_D) of ZLS

Parameter	Source of Variation	Sum of Squares	df	F	*P*
TP	Thickness	5294.764	1	794.086	<.001*
	Translucency	59.766	1	8.963	.003*
	Fabrication method	18.534	1	2.780	.098
	Storage solution	0.031	1	0.005	.945
OP	Thickness	993.046	1	401.026	<.001*
	Translucency	1.401	1	0.566	.453
	Fabrication method	96.426	1	38.940	<.001*
	Storage solution	0.107	1	0.043	.836
WI_D	Thickness	285.136	1	10.504	.001*
	Translucency	51.519	1	1.898	.170
	Fabrication method	334.855	1	12.336	<.001*
	Storage solution	57.434	1	2.116	.148

df, degrees of freedom (N-1);ZLS, zirconia-reinforced lithium silicate glass-ceramic. *statistically significant ($P < .05$), within subject factor time.

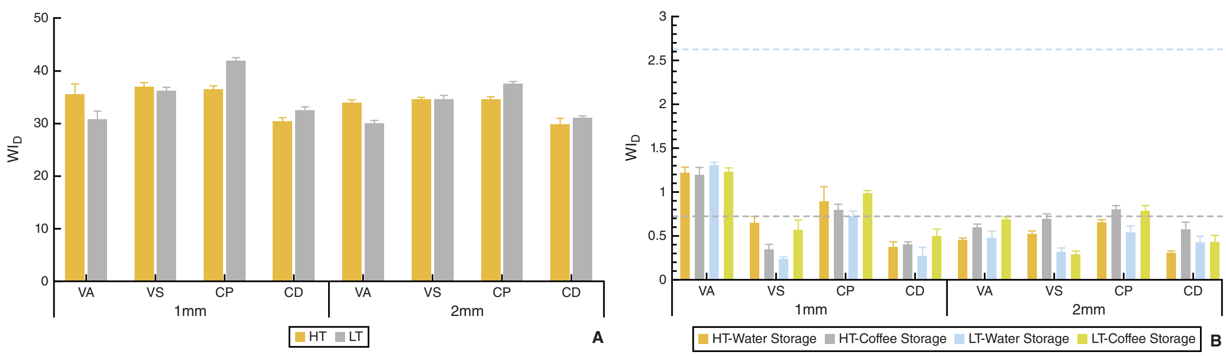

Figure 4. Whitening index (WI_D) of zirconia-reinforced lithium silicate ceramics in different thickness and translucency levels. A, At baseline (T_0). B, ΔWI_D after bleaching. *Horizontal blue line* represents ΔWI_D acceptability threshold. *Horizontal gray line* represents ΔWI_D perceptibility threshold. CD, Celtra Duo; CP, Celtra Press; HT, high translucency; LT, low translucency; VA, VITA AMBRIA; VS, VITA Suprinity.

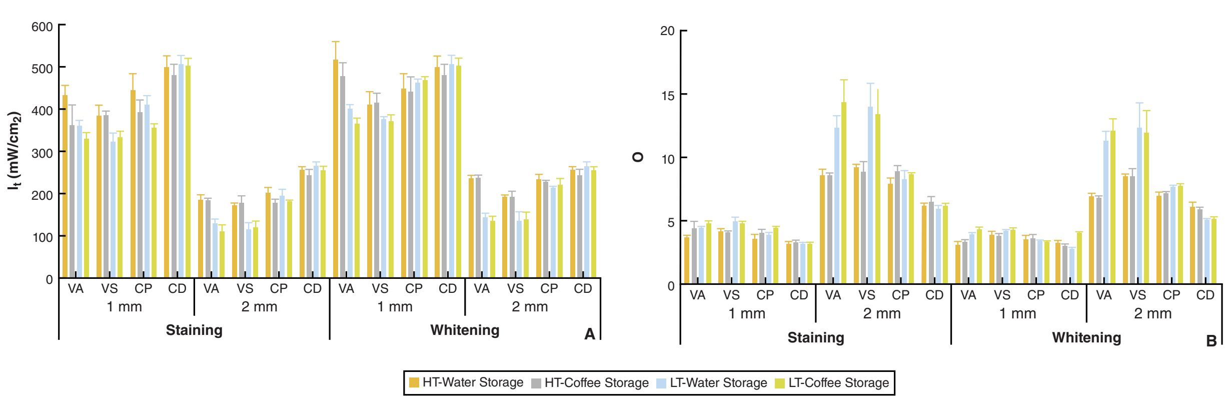

Figure 5. Zirconia-reinforced lithium silicate ceramics of different thickness and translucency levels after staining and bleaching treatment. A, Transmitted irradiance (I_t). B, Opacity (O). CD, Celtra Duo; CP, Celtra Press; HT, high translucency; LT, low translucency; VA, VITA AMBRIA; VS, VITA Suprinity.

studies[12,77] and were attributed to differences among ZLSs in terms of composition, crystal size (Table 1), and crystalline to glass phase ratios.[2,9,35,38,77] The translucency of human teeth ranges from 15<TP<19 at 1-mm thickness, and restorative materials exhibit TP up to 25.[41,42] In the current study, TP was highest in 1-mm-thick CP materials (15.8<TP<16.6) and lowest in all the ZLS materials of 2-mm thickness,

Table 5. Repeated measures four-way ANOVA table for transmitted irradiance (I_t), light transmission (T), and opacity (O) of ZLS

Parameter	Source of Variation	Sum of Squares	df	F	*P*
I_t	Thickness	6865518.408	1	911.780	<.001*
	Translucency	135878.700	1	18.045	<.001*
	Fabrication method	18228.675	1	2.421	.122
	Storage solution	4025.208	1	0.535	.466
T	Thickness	2.595	1	815.331	<.001*
	Translucency	0.054	1	16.945	<.001*
	Fabrication method	0.017	1	5.240	.024*
	Storage solution	0.003	1	0.899	.345
O	Thickness	2875.636	1	287.040	<.001*
	Translucency	203.751	1	20.338	<.001*
	Fabrication method	26.025	1	2.598	.109
	Storage solution	3.994	1	0.399	.529

df, degrees of freedom (N-1); ZLS, zirconia-reinforced lithium silicate glass-ceramic. *statistically significant (*P* < .05), within subject factor time.

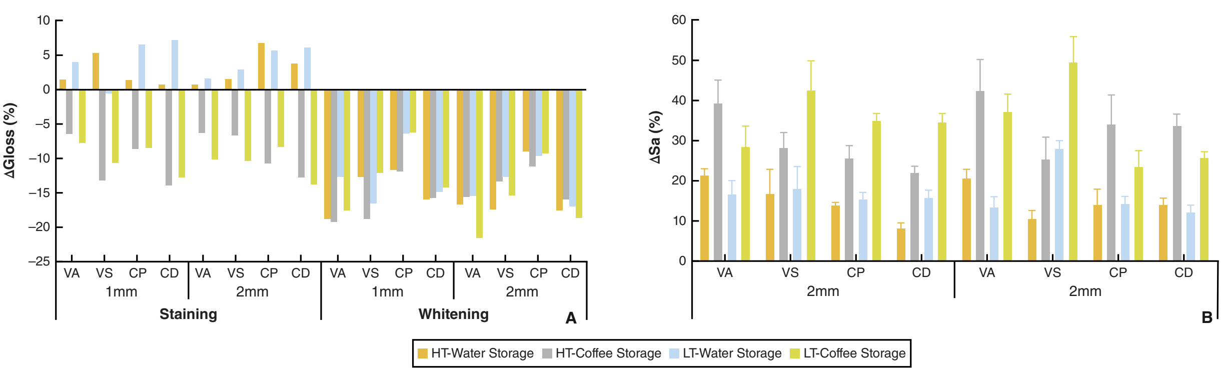

Figure 6. Zirconia-reinforced lithium silicate ceramics of different thickness and translucency levels after staining and bleaching treatments. A, Change in gloss (ΔGU%). B, Change in roughness (ΔSa %). CD, Celtra Duo; CP, Celtra Press; HT, high translucency; LT, low translucency; VA, VITA AMBRIA; VS, VITA Suprinity.

Table 6. Four-way ANOVA table for ZLS gloss stability (ΔGU%) after staining (T_1) and bleaching (T_2) and ZLS roughness stability (ΔSa%) after bleaching (T_2)

Parameter	Time	Source of Variation	Sum of Squares	df	F	*P*
ΔGU%	T_1	Thickness	4.914	1	0.257	.613
		Translucency	11.493	1	0.601	.440
		Fabrication	126.285	1	6.599	.011*
		Storage Solution	7194.208	1	375.941	<.001*
	T_2	Thickness	18.614	1	0.646	.423
		Translucency	74.985	1	2.600	.109
		Fabrication	202.922	1	7.037	.009*
		Storage Solution	21.735	1	0.754	.387
ΔSa%	T_2	Thickness	42.981	1	1.057	.306
		Translucency	233.998	1	5.755	.018*
		Fabrication	17.024	1	0.419	.519
		Storage Solution	10881.7	1	267.626	<.001*

df, degrees of freedom (N-1); ZLS, zirconia-reinforced lithium silicate glass-ceramic.
*statistically significant (*P* < .05).

ranging from 4.5 in VA up to 8.6 in CP. The small crystal size of CP could be responsible for its high translucency (0.41 ±0.13 µm for fired CP and 0.48 ±0.11 µm for fired CD).[78]

The opalescence parameter ranges from 18 to 22 for human teeth and 5 to 13 for monolithic ceramics.[37,43,44] In the current study, the OP values of ZLSs were higher than those reported in the literature for lithium disilicate,[37,40] attributed to the incorporation of ZrO_2 into the glassy matrix of ZLSs. Conversely, the OP of ZLS specimens (5.1 to 10.8) was lower than that reported in other studies (OP=12.6) for specimens of similar thickness (1 mm).[37] The difference is most likely explained by the staining and bleaching performed, which altered the OP of ZLSs.

Different indices have been used to quantify whiteness in dental materials.[45–47] The present study used the most recent whiteness index (WI_D)

customized for dental materials and reported to outperform previous indices.[48] The bleaching agent contained 1.5% hydrogen peroxide (Table 1) and was chosen for its efficacy in eradicating yellowish discoloration leading to true whitening results.[27] At baseline, the ZLSs exhibited WI_D>30 (Fig. 4A), similar to the WI_D values of esthetic dental materials reported previously.[79,80] After bleaching, none of the ZLSs exceeded the WI_D acceptability threshold; however, 1-mm-thick VA, CP, and CD surpassed the ΔWI_D perceptibility threshold. ZLS restorations have been reported to exhibit better bond strengths and mechanical properties when luted to resin cements.[81] Inadequate photoactivation of light-polymerized resin cements can reduce their degree of conversion and, subsequently, lower flexural strength and increased solubility.[52,53] In the current study, increasing ZLS thickness significantly decreased I_t (Fig. 5A), which has also been reported previously,[54,55,82] while bleaching increased the I_t of ZLS ceramics to differing extents. Coffee staining of 2-mm-thick ZLSs strongly influenced their opacity (Fig. 5B). These results were consistent with those reported in the literature[17,83] and can be attributed to the coffee solution's low pH and high staining potential that alters the degree of light transmission of ZLSs.

In the present study, both acidic media (coffee and bleaching mouthwash) significantly reduced ZLS gloss (up to 20%) (Fig. 6A). On the contrary, water storage had an effect on gloss retention because of the smooth water film adsorbed onto ZLS surfaces, mimicking the effect of saliva.[63–65] Different findings have been reported regarding the effect of bleaching agent type, concentration, contact time, and frequency on ceramic roughness.[25,66,67] In the present study, ZLS roughness significantly increased after bleaching, which could be associated with the acidic nature of mouthwash (pH=4.9), resulting in the chemical degradation of superficial crystalline structures and, consequently, surface profile alteration.[84]

Limitations of the study included that all experiments were executed on a single shade of flat ceramic plate; as a result, findings cannot be generalized to multidimensional restoration morphologies in different shades. Furthermore, immersed specimens were stored at 37 °C, which does not accurately simulate temperature variations in the oral cavity. Future in vitro studies exploring the effects of polishing protocols on ZLS properties after extended coffee staining and bleaching could enhance the clinical relevance of the findings.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The thickness of ZLSs influenced color stability, whiteness, translucency, opalescence, transmitted irradiance, light transmission, and opacity.
2. ZLSs fabricated by different methods exhibited different degrees of color stability, whiteness, opalescence, and light transmission.
3. Dissimilar translucency levels impacted whiteness stability, transmitted irradiance, light transmission, and opacity of ZLSs.
4. Exposure to acidic media was detrimental to the colorimetric and topographic properties of ZLSs.

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